

SEISMIC ASSESSMENT OF STOCK BUILDINGS FROM THE 1960s IN KOSOVO: AN INTEGRATED ANALYTICAL AND EXPERIMENTAL APPROACH

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ABSTRACT

Buildings constructed during the 1960s constitute a substantial portion of the existing building stock in Kosovo, typically characterized by frame-type systems with infill walls, as well as mixed constructions combining masonry and cast-in-place concrete. These buildings were designed and built in a period when seismic design criteria were not systematically incorporated into building codes, rendering them particularly vulnerable to seismic risk under current usage conditions. This study develops an integrated approach for assessing seismic risk in these structures, combining in-situ testing, laboratory analysis of existing materials, and advanced numerical modeling based on nonlinear pushover analysis. Within this framework, dynamic characteristics are identified through ambient vibration testing, and structural capacity is compared with seismic demand in accordance with Eurocode 8. To synthetically represent structural performance and risk, the Vulnerability Index (VI) is used as an analytical indicator, enabling cross-typology comparisons and helping prioritize intervention strategies. To reduce risk and enhance both load-bearing capacity and ductility of existing structures, different intervention strategies are examined. Alongside conventional strengthening methods, the analysis includes proposals for new techniques and materials, emphasizing the use of Fibre Reinforced Polymers (FRP). FRP materials offer lightweight solutions with minimal impact on structural mass and architectural appearance, making them suitable even for buildings of historical or cultural significance. The application of these technologies provides a sustainable approach to modernizing the old building stock in the region, preserving functional and architectural integrity while improving seismic performance in line with contemporary engineering standards.

Keywords: Masonry buildings, Seismic vulnerability, Structural behavior, FRP, Load-bearing capacity

1. INTRODUCTION

Masonry buildings constructed during the 1960s represent a significant portion of the building stock in Prishtina, sharing similar design concepts and construction characteristics. In general, architectural layouts, structural configurations, materials, and construction techniques are comparable across this building group. The main concern is the application of regulations at the time, which were limited regarding structural behavior under seismic effects, resulting in considerable damage during earthquakes in the region. Furthermore, the long-term use of these typical buildings, often without significant maintenance or intervention, has limited their service life due to the effects of aggressive environmental conditions. The seismic performance of masonry structures is closely related to material properties, the interaction between elements (e.g., clay blocks and mortar), and, in some cases, cooperation with reinforced concrete elements. This paper focuses on assessing the seismic behavior of these structures, applying analytical methods supported by prior research (analytical modeling, pushover analysis, and spectral analysis), as well as experimental methods for material characterization (both non-destructive and destructive). Using these data, the study analyzes the potential for structural improvements and enhances understanding of load-bearing capacity, with particular emphasis on strengthening using FRP materials and techniques. The analyses and evaluations also provide technical recommendations for structural reinforcement and seismic risk management.

2. FACTORS INFLUENCING THE BEHAVIOR OF UNREINFORCED STRUCTURES

The study aims to establish comparability between theoretical predictions and the observed behavior of structures during recent earthquakes, such as those in Albania (November 2019) and Croatia (March 2020). The selected buildings for analysis are masonry structures from the 1960s in Kosovo, mainly in the Ulpiana–Prishtina area, as well as similar collective residential buildings up to five stories high, constructed according to the former JUS standards. As a reference, observed damage in similar structures in Albania and Croatia—belonging to the same construction category—is used for comparison, as illustrated in Fig. 1(a, b, c).



Fig. 1: (a) Behavior of buildings in Albania; (b) Buildings in Pristina; (c) Behavior of buildings in Croatia.

In the preliminary analyses and evaluations, several factors influencing the behavior of unreinforced structures were identified in relation to the observed damage:

- Low load-bearing capacity of masonry elements;
- Inadequate load-bearing capacity and poor quality of mortar;
- Lack of regularity in plan and low load-bearing capacity of walls;
- Design and construction errors in vertical elements;
- Errors and interventions in ground floors;
- Redistribution of space or openings in walls;
- Overall stiffness of the structure as a whole.

Interventions on ground floors are a common practice, often motivated by changes in space usage, and are frequently carried out in an uncontrolled manner. Post-earthquake case studies and observed behavior of masonry structures indicate that such interventions significantly limit structural ductility, directly reducing load-bearing capacity and the overall strength of the masonry material. The use of low-quality mortars and their improper application further reduce masonry resistance, contribute to crack formation, and decrease the shear capacity of walls.

3. SEISMIC PERFORMANCE ASSESSMENT OF STRUCTURES

Research and findings by numerous authors in the field of seismic risk assessment provide a deeper understanding of the behavior of masonry structures and reinforced concrete (RC) frames with infill walls (Dautaj *et al.* 2018a). Under seismic loading, masonry infills often sustain damage without causing immediate structural collapse; however, they may contribute to the development of soft-story mechanisms (Pauley *et al.* 1992).

The appearance of diagonal cracks enables the identification of failure modes, which, in some cases, involve the formation of plastic hinges at the connections between columns and upper floors (Fig. 2). This figure illustrates the equivalent diagonal strut model used to represent the behavior of masonry infill walls within RC frames under lateral loading.

In this model, the infill transfers most of the horizontal force along a compressed diagonal band, which is mechanically represented as a single diagonal strut with an effective width and angle. This simplified model captures the stiffening effect of the infills and their interaction with the surrounding RC frame during seismic events. A numerical modeling approach illustrating this behavior is presented in Fig. 3.

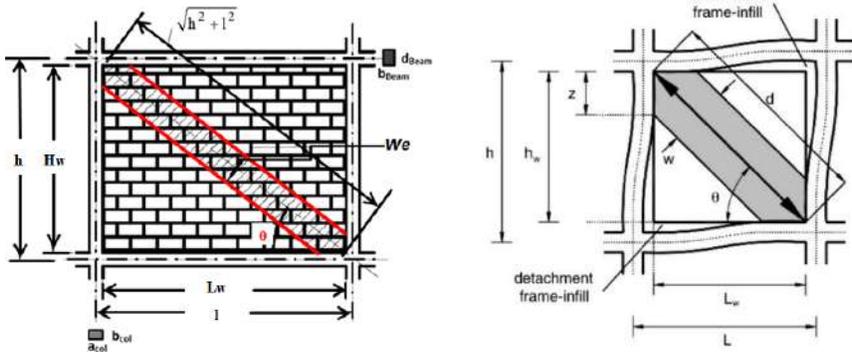


Fig. 2: The tangential sliding model of infill masonry (Paulay and Priestly, 1992).

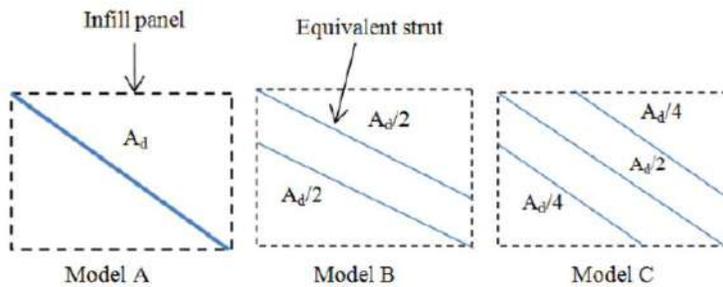


Fig. 3. Different models for the analysis of infill masonry.

In the framework of structural performance assessment and analytical calculations, it is necessary not only to evaluate relative displacements but also to determine the maximum absolute displacement that may occur at a given point in time. This enables the identification of the maximum seismic force acting on the analyzed structure. To this end, several earthquake accelerograms from different countries are considered, alongside the corresponding elastic response spectra based on the EN 1998-1 standard. Figure 4 presents a comparison between real earthquake response spectra (Beograd, Petrovac, El Centro, Ulcinj) and the elastic design spectra defined by Eurocode 8 (EC8) for different soil types (A, B, C, D), using a behavior factor $q=1.0q = 1.0q=1.0$, which corresponds to no reduction for ductility.

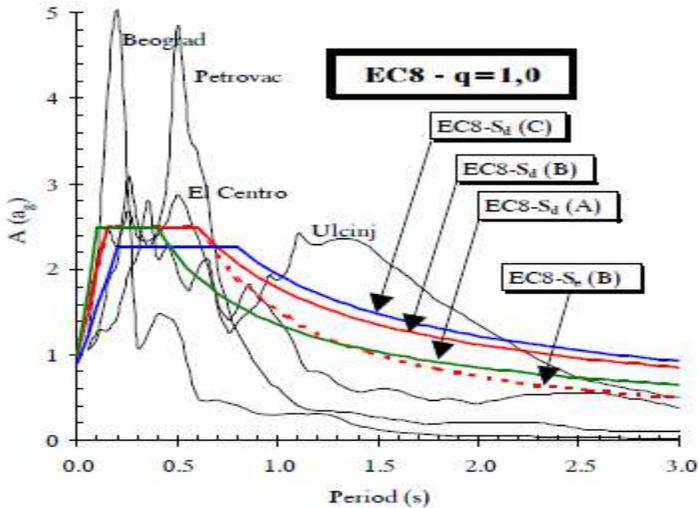


Fig. 4. Elastic acceleration spectra of earthquakes in different locations.

3.1. Seismic Performance of Masonry Structures – General Data

A key aspect in evaluating the seismic performance of masonry structures is the assessment of their vulnerability, which is closely influenced by a range of factors. These factors affect both the determination of the vulnerability class and the overall evaluation of seismic risk as part of a structured analysis procedure. The relevant evaluation factors are summarized in Table 1.

Table 1. The respective factors

High Vulnerability	Low Vulnerability
Insufficient quality of materials (weak mortar, fragile/weak units), poor internal bonding of masonry (irregular undressed stones, multi-leaf masonry without transverse connections, etc.).	Regular and durable units, good bonding and interlocking between units; masonry behaves as a monolithic whole throughout the wall thickness.
Very thin walls (susceptible to out-of-plane instability).	Limited wall slenderness; resistance to out-of-plane failure.

Lack of effective connections between walls and between walls and horizontal structures; absence of structural redundancy.	Good interconnection at wall corners, presence of tie rods and ring beams at each floor (and roof) level to enable “box action”; effective wall–floor connections that reduce stress concentrations.
Intermediate floor systems do not act as diaphragms.	Floors sufficiently stiff and resistant to provide out-of-plane support for walls, increase structural redundancy, and allow redistribution of internal forces.
Presence of horizontal thrusts (e.g., from roofs or arched/vaulted structures) resisted only by the out-of-plane resistance of walls.	Horizontal thrusts resisted by in-plane action of strong/bracing walls or by suitable structural elements (tie rods, floor diaphragms), forming a closed equilibrium system.
Excessive unsupported floor spans, walls widely spaced and irregularly distributed.	Limited floor spans; shear walls regularly distributed in at least two orthogonal directions.
High structural and non-structural masses and low material strength.	Masses and weights produce a low compression/strength ratio.
Structural irregularities in plan (torsional effects, stress concentrations) and in elevation (inefficient load paths, stress concentrations).	Regular structure, sufficient resistance to torsion, regular load path from top to foundations.

One of the main objectives of using these factors is classify structures according to the data reported in the authors (Cosenza *et al.* 2004) and presented in Table 2.

Table 2. Classification of masonry structures

	Non-Engineered (NE)	Engineered (E)
Structurally Inadequate (NS)	NSNE	NSE
Structurally Adequate (SD)	SDNE	SDE

4. CASE STUDY – SEISMIC RISK ASSESSMENT

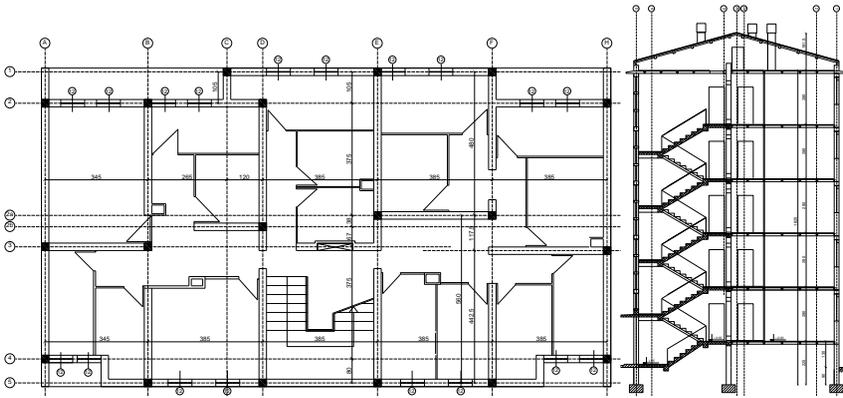


Fig. 5: Geometry of typical floor plan.

To evaluate the behavior of the structure, including its seismic response, several material tests and full-scale structural assessments were carried out. The building selected for this study is a six-story structure constructed in the 1960s in the Ulpiana district of Prishtina. It represents part of a complex of repetitive buildings with similar geometric and structural characteristics. The structure consists of a reinforced concrete (RC) frame with brick infill walls, built using the construction technologies of that period, including horizontal RC beams and concrete of varying quality between the lower and upper floors. With a layout of five bays in the X-direction and two in the Y-direction, the building features spans of up to 3.85 m and 5.60 m, and incorporates reinforcement with $\text{Ø}16$ mm and $\text{Ø}14$ mm steel bars in the columns of different floors. This building typology is representative of mid-20th-century construction in Kosovo, which today faces considerable challenges in meeting modern seismic design requirements. The methodology applied in this case study is summarized in Table 3.

During the Ambient Vibration Testing (AVT), a set of tri-axial accelerometers from the Digitex AVM system was installed. The sensors recorded ambient motion at a sampling rate of 200 Hz, which is adequate for identifying modal frequencies within the typical range for mid-rise masonry and RC buildings (0.5–15 Hz). Schmidt hammer testing was performed in accordance with EN 12504-2, using a Type N rebound

hammer. Before each testing session, the instrument was calibrated using a standard steel anvil as recommended by the manufacturer. Each flat jack was calibrated in the laboratory using a steel reaction frame and hydraulic pump to establish the pressure–volume curve, and a reference pressure gauge with $\pm 0.2\%$ accuracy was used for calibration of the pressure cell.

Table 3. Followed methodology

Chapter	Methodology	Main Results
1. Description of the Building	On-site inspection; Analysis of structural layout; Identification of key geometric and material characteristics	Six-story RC frame building with infill walls; Repetitive design in the neighborhood
2. Ambient Vibration Tests and Model Calibration	Non-destructive AVT tests with accelerometers; Processing with EFDD; Calibration with 3D numerical model	Four global modal shapes identified; Good agreement between model and tests; Effect of confined masonry clearly observed
3. Material Characterization	Schmidt hammer test for in-situ concrete; Laboratory tests for masonry bricks according to EN standards	Concrete showed higher strength than originally designed; Bricks had strength of 16–24.3 N/mm ²
4. Nonlinear Static Analysis and Parametric Study	Pushover analysis with different load patterns; Parametric variations of masonry and concrete properties	Masonry increased shear capacity by 35–40%; Stronger concrete added 10–15%; Confined masonry improved calibration

4.1. In-Situ And Laboratory Material Characterization

To assess the actual condition of the construction materials, in-situ tests were conducted on concrete using the Schmidt Hammer method (EN 12504-2), while laboratory tests were performed on clay bricks in accordance with the relevant EN standards. The results showed that the concrete in the main structural elements demonstrated higher strength than

originally designed, indicating no significant degradation and stable mechanical properties. Compressive strength tests on masonry bricks yielded average values ranging from 16 to 24.3 N/mm², confirming considerable load-bearing capacity under seismic actions. This detailed evaluation provided a reliable basis for accurate structural modeling and for understanding the influence of masonry on the building's seismic behavior. Clay brick testing was performed in accordance with EN 772-1. The samples were prepared and analyzed, and the results are summarized in Table 4.

Table 4. Brick test results.

Sample	Force [kN]	Compressive Strength [N/mm ²]	Average Compressive Strength [N/mm ²]	Shape Factor [d]	Normalized Compressive Strength [N/mm ²]
M1 & M2	770.5	24.3	21.3	0.75	16.0
M3 & M4	706.1	23.5			
M5 & M6	460.5	16.0			

4.2. “Flat JACK” testing

Flat-jack examinations were conducted on a wall at the ground-floor level to assess its mechanical characteristics as an integral component of the structure. The test results provided essential parameters for the structural analysis. An illustration of the setup is shown in Fig. 6.

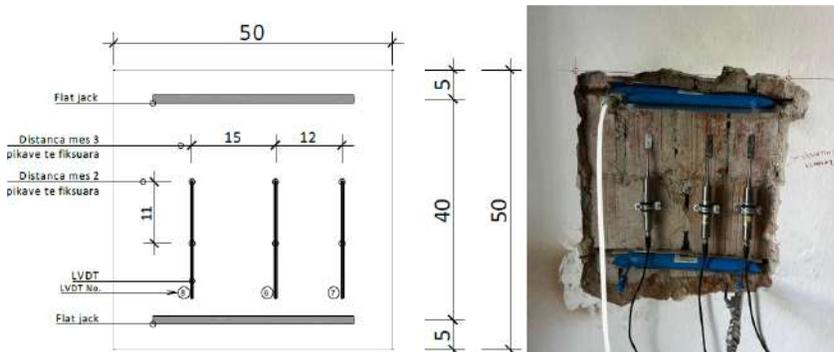


Fig. 6: Setup scheme for the positioning of the ‘Flat Jack’ device.

The evaluation was performed after completing the necessary preparations on the wall subjected to testing, following the scheme illustrated in Fig. 6. The results of the examinations are presented in Fig. 7, incorporating the previously calibrated measurements used for the final assessments. The graph shows the outcomes of the flat-jack test, displaying the increase in stress (MPa) in relation to the measured deformation (mm/mm) for two different instruments: the average readings from the LVDTs and Strain Gauge 6. Both data sets follow clear linear trends, indicating that the masonry exhibited elastic behavior within the applied load range.

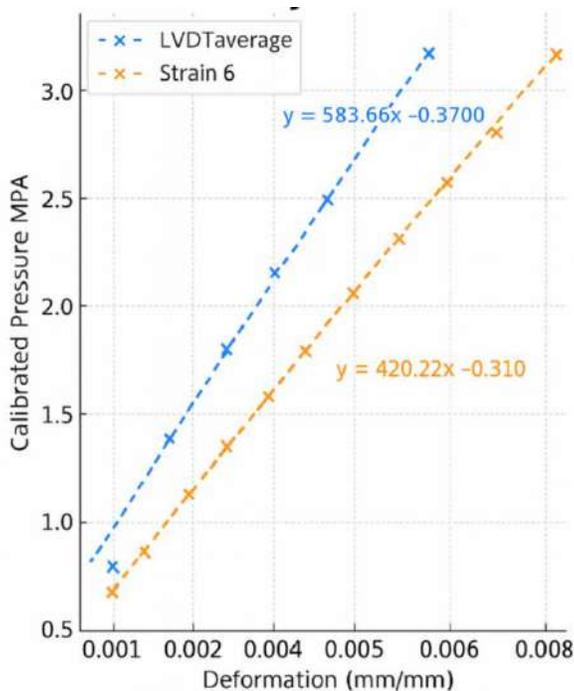


Fig. 7: The obtained results and the Pressure/Deformation ratio.

4.3. Ambient Vibration Tests and Model Calibration

To evaluate the dynamic behavior of the existing building, the non-destructive method of Ambient Vibration Testing (AVT) was applied. This technique enables the identification of natural frequencies, modal shapes,

and damping ratios by analyzing the structure's response to environmental excitations. Accelerometers were strategically installed on each floor, and the recorded data were processed using the Enhanced Frequency Domain Decomposition (EFDD) method. A total of eight modal shapes were identified, of which four were global modes—corresponding to movement in the X- and Y-directions and one torsional mode. These results were then used to calibrate a 3D numerical model developed using SeismoStruct and ETABS software, thereby improving the accuracy of the analyses and emphasizing the significant role of confined masonry in enhancing the structure's seismic performance. The equipment used was the Digitex AVM System, consisting of a central processing unit and multiple sensing components for data acquisition, as illustrated in Fig. 8.

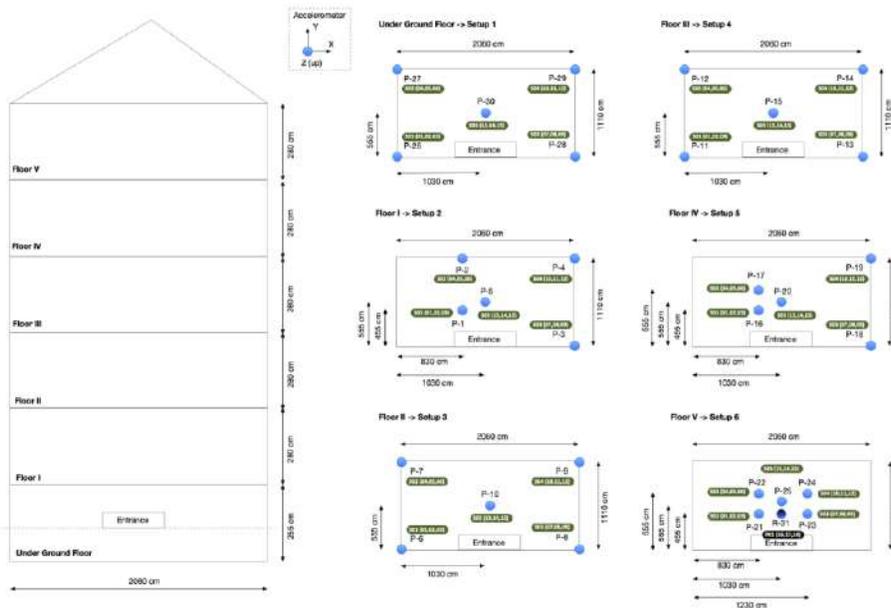


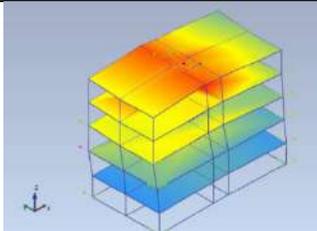
Fig. 8: Positioning positions of sensors.

The results of the analyses and the corresponding evaluations are presented in Tables 5 and 6, based on the processing performed using the FDD and EFDD methods.

Table 5. Different parameters given as results from the testing.

Mode Shape	Description	FDD f (Hz)	T (s)	EFDD f (Hz)	T (s)	ξ (%)	MAC
1	First translational mode in Y-direction + slight rotation	3.711	0.269	3.711	0.269	/	0.7453
2	First translational mode in X-direction + slight rotation	4.102	0.244	4.102	0.244	/	0.0915
3	First torsional mode in XY plane	5.518	0.181	5.518	0.181	/	0.5995
4	Second translational mode in Y-direction + slight rotation	5.762	0.174	5.762	0.174	/	0.7032
5	Local mode	6.665	0.150	6.665	0.150	/	0.150

Table 6. Testing results, core information.

Mode shape	Description	f(Hz)	T(sec)	
1	Translations in Y direction slight rotation	3.711	0.269	
2	Translations in X direction slight rotation	4.102	0.244	
3	Torsion	5.5.18	0.181	

4.4. Nonlinear Static Analysis and Parametric Study

To establish comparability and enable a more detailed assessment, an analytical model was developed by incorporating all relevant geometric and material parameters using SeismoBuild software. Nonlinear static

(pushover) analyses were carried out to evaluate the seismic capacity of the structure by applying incrementally increasing lateral loads. Several simulation scenarios were considered, involving variations in the mechanical properties of concrete and masonry, including the introduction of confined masonry in strategic areas such as the building perimeter and main corridors.

The results demonstrated that the addition of confined masonry and the improvement of concrete quality significantly increased the base shear capacity and reduced displacements at the defined limit states—Damage Limitation (DL), Significant Damage (SD), and Near Collapse (NC). Specifically, the use of higher-strength masonry increased capacity by up to 40%, while the application of higher-quality concrete contributed an additional 10–15%. The calibration of the capacity curves using field-test data underscores the importance of experimental validation in the seismic assessment of existing buildings and in the development of targeted strengthening strategies.

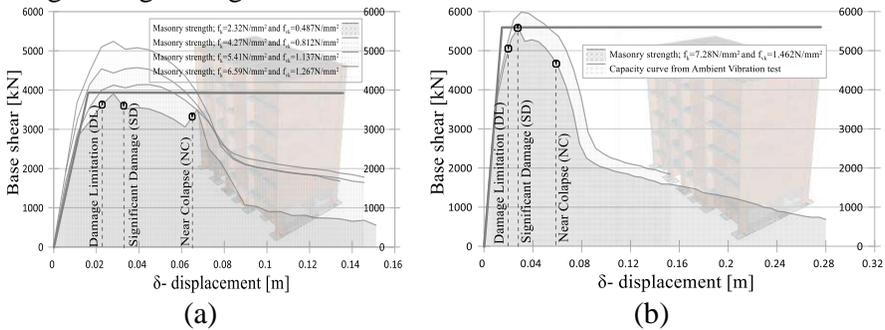


Fig. 9: Calibration of capacity curves: (a) Influence of masonry properties on structural dynamic behavior; (b) Field-test-based comparison.

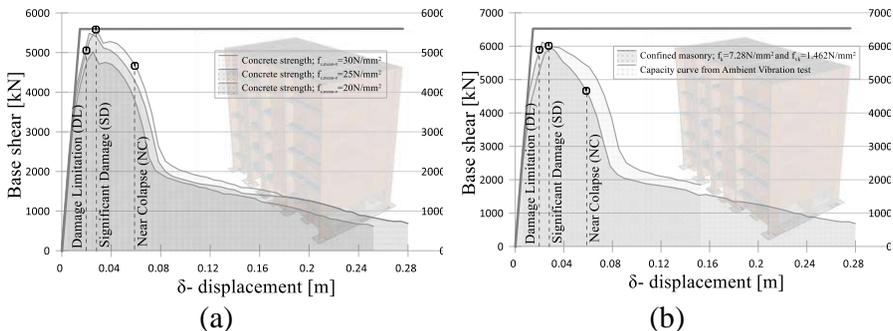


Fig. 10: Calibration process of capacity curves; (a) impact of concrete strength, (b) calibration considering confined masonry.

Figures 9 and 10 provide graphical representations that help the engineer better understand how variations in masonry and concrete properties influence the shape and behavior of capacity curves. These visual comparisons facilitate the observation of how changes in material strength, stiffness, and confinement affect the structural response, thereby enabling clearer interpretation and more accurate calibration of analytical models. Similar approaches, including investigations of the influence of infill walls on the global behavior of structures, have also been studied by Santarsiero *et al.* (2021), Martin Leal-Graciano *et al.* (2020) and Moreira *et al.* (2023).

5. THE RELATIONSHIP BETWEEN SEISMIC RISK AND VULNERABILITY

Various approaches that attempt to incorporate multiple factors as an “interlinked chain” have predominantly focused on the final outputs of seismic risk, without thoroughly exploring the behavior of risk itself (Alwang *et al.* 2001). This gap exists because risk behavior is difficult to characterize and requires specific considerations for proper evaluation. A conceptual illustration of the influence of vulnerability on seismic risk is presented in Fig. 10, accompanied by explanatory notes.

5.1. Seismic Risk and Risk Exposure

Vulnerability begins with the notion of risk, which is characterized by the distribution of unpredictable scenarios. An example of risk categorization is provided by Alwang (2000).

Table 7. Types of Risk according the Jorgeson

Risk Category	Example of Risk
Natural risk	Floods, landslides, earthquakes, hurricanes, storms, etc.
Health risk	Epidemics, mass outbreaks
Life-cycle risk	Birth, aging, death, etc.
Social risk	Violence, terrorism, wars, etc.
Economic risk	Business bankruptcies, financial crises, etc.
Political risk	Discrimination, coups d'état, etc.
Environmental risk	Environmental pollution, land degradation, nuclear disasters, etc.

Within the framework of seismic risk assessment, the parameters required for calculating the vulnerability index are presented below. These parameters serve as key evaluation criteria for masonry structures. They are classified into three assessment levels—L (Low), M (Medium), and H (High)—and the indicative values corresponding to each category are provided in Table 7.

Table 8. Parameters for the assessment of the vulnerability index in masonry structures, categorized according to the evaluation scale: L (Low), M (Medium), and H (High).

#	Parameter	L (Low)	M (Medium)	H (High)
1	Connection between orthogonal walls	0	10	28
2	Quality of masonry	–	–	17.5
3	Connection between load-bearing walls and non-structural components	0	8.5	17
4	Spacing of load-bearing walls	0	5	9
5	Type of intermediate floor and its connection to the wall	0	4	7.5
6	Horizontal offsets of load-bearing walls	–	–	6.5
7	Regularity in plan	–	–	6
8	Type of roof and its connection to the walls	0	2	4.5
9	Vertical offsets of floors and arches	–	–	4
10	Position and interconnection of structural units as a whole	0	1	4

The Vulnerability Index (V_i) is derived from the statistical relationship between seismic intensity—evaluated from historical earthquake data—and the performance of different structural classes, combined with accumulated knowledge from typical damage assessments (Benedetti and Petrini, 1984; Marco *et al.* 2021).

5.2. Strengthening and preventive Measures in Minimizing Seismic Risk in Masonry Structures

Strengthening the existing building stock represents a key preventive measure for reducing earthquake-related damage, particularly in residential and public buildings. Effective and optimized strengthening interventions for existing masonry structures require a precise analysis and an accurate determination of vulnerability levels, taking into account construction typology and traditional building practices (Scupin and Vacareanu, 2023). When defining fragility parameters for various typologies—such as those analyzed through numerical models in this case study—a clear and systematic approach is necessary for selecting appropriate methodologies and materials for structural strengthening. The assessment of damage levels serves as a basis for determining spectral deformation values, which are closely connected to the probability of failure in masonry structures (see Fig. 11).

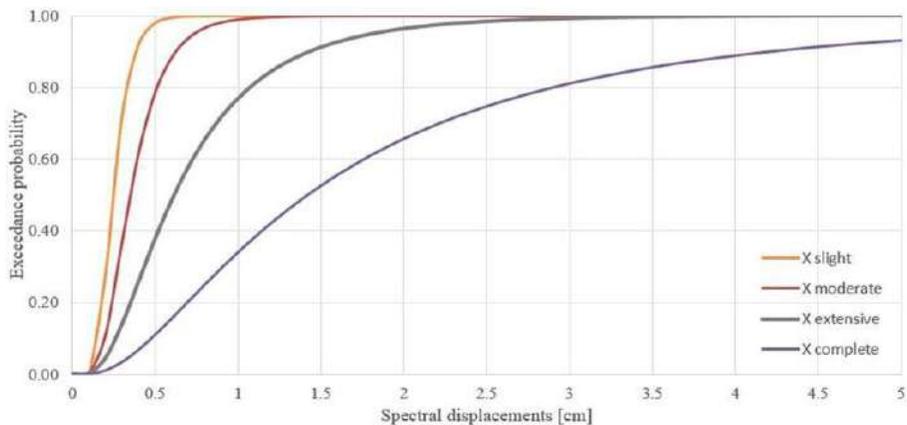


Fig. 11. Fragility curve.

The vulnerability of masonry structures necessitates several approaches and hypotheses for strengthening, with a focus on the application of contemporary methods and materials such as Fiber Reinforced Polymers (FRP) (Ahani *et al.* 2021). Existing structures often demonstrate seismic deficiencies and require strengthening at suitable and accessible locations (Sarker *et al.* 2011). Based on the model presented previously in Fig. 6, this study explores the use of FRP diagonal

reinforcement—as shown in Fig. 12—specifically the application of FRP strips functioning as tensile elements. These elements exhibit significant potential for improving the ductility of the structure and its individual components (Benedetti and Petrini, 1984; Kabashi *et al.* 2016; Moriera *et al.* 2023).

Because the flexural capacity and deformation resistance of masonry walls are inherently limited, the high tensile strength of FRP materials can effectively compensate for these deficiencies (Dautaj *et al.* 2018b).

Figure 12 illustrates the experimental setup and results for a masonry wall strengthened with X-shaped diagonal FRP reinforcement, together with the corresponding load–displacement curve obtained from cyclic testing. The images on the left show the reinforced wall configuration, while the graph on the right presents the structural response under increasing lateral displacement, including loading cycles, progressive stiffness degradation, and peak load capacity prior to softening. Together, the visual materials provide a clear understanding of the behavior of strengthened masonry under cyclic loading and the evolution of its load-bearing capacity.

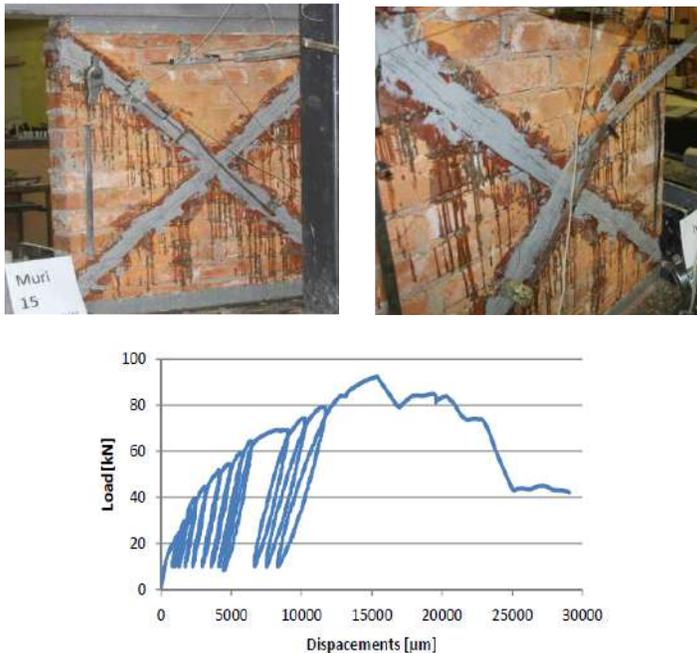


Fig. 12. a) Testing, reinforced walls. b). Displacement of the testet system.

5.3. Cost–Benefit Analysis

Strengthening masonry structures with FRP (Fiber Reinforced Polymer) materials offers a highly cost-effective and efficient solution for enhancing structural resistance and ductility, particularly under seismic loads. While the initial costs may be higher compared to traditional interventions, the long-term benefits and reductions in secondary impacts caused by seismic events justify the investment (Yavartanoo *et al.* 2025). The main cost–benefit aspects include:

- Lower overall cost compared with many traditional strengthening techniques
- Rapid implementation and reduced construction time
- Minimal increase in the total weight of the structure
- Ease of installation and on-site application
- Significant improvement in structural performance
- Reduction of unforeseen risk during extreme events

6. CONCLUSIONS

A considerable number of masonry structures from the 1960s were not designed in accordance with modern seismic provisions. For this reason, strengthening measures—aligned with contemporary design codes—are strongly recommended as a preventive strategy to reduce potential earthquake-induced damage (Sarker *et al.* 2011).

The building analyzed in this study forms part of a larger stock of repetitive mid-20th-century residential structures, many of which share comparable geometry, material characteristics, and construction techniques within the same neighborhood in Prishtina. Thus, this case study provides representative insights into a broader category of similar buildings. However, restricted access to a complete inventory prevents the confirmation of whether internal configurations or past interventions are consistent across the entire stock. Furthermore, while this construction pattern is not representative of the entire region, it typifies a significant portion of the capital city’s mid-century building inventory.

Regarding strengthening strategies, the application of FRP materials emerges as an effective alternative to conventional methods due to their advantageous properties, including:

- High elastic modulus (stiffness)
- High mechanical strength
- Excellent corrosion resistance

- Low weight and ease of application

Based on the analyses conducted in this study, the following main conclusions can be drawn:

- Strengthening with FRP can lead to a substantial increase in elastic stiffness, thereby reducing structural damage during seismic actions.
- GFRP (Glass Fiber Reinforced Polymer) is particularly well suited for strengthening walls with openings, especially when reinforcing the perimeter of these openings.
- Understanding the behavior of FRP-strengthened systems helps improve failure mechanisms, which are typically brittle under cyclic loading.
- Current design codes provide reliable guidance for FRP strengthening and are expected to play an even more significant role in the next generation of standards.
- The application of FRP systems requires specialized training for the technical personnel involved in on-site implementation.
- Although the cost of FRP strengthening remains relatively high compared to traditional methods, this limitation is often offset by the numerous advantages of FRP systems, including their lightweight nature, ease of installation, minimal impact on structural mass, and high efficiency in improving structural performance.

Data accessibility:

There are no datasets associated with this study that require public deposition. However, all numerical models, analysis scripts, and computational codes used in this work are available from the corresponding author upon reasonable request

Declaration of AI use

AI tools (including ChatGPT) were used exclusively for improving formulation, grammar, and clarity of the text, and not for generating scientific content, data analysis, conceptual development, or interpretation of results. All scientific ideas, methods, data processing, calculations, and conclusions were fully developed by the authors.

Authors' contributions:

NK, - Conceptualization; methodology; supervision; validation; writing—review and editing;

EK,-Formal analysis; numerical modelling; investigation; writing—original draft; writing—review and editing; YM,- Data curation; resources; investigation; visualization; writing—review and editing.

Authors's approval

All authors have read and approved the final version of the manuscript and agree to be held accountable for all aspects of the work.

Conflict of interest declaration

The authors declare there are no conflicts of interest.

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REFERENCES

- Ahani E, Osmanzadeh F, Mousave MN, Rafezy B. 2021.** In-plane retrofitting of masonry structures by using GFRP strips in the bedjoints, 10.21203/rs.3.rs-711691/v1.
- Alwang J, Siegel PB, Jorgensen SL. 2001.** Vulnerability: A view from different disciplines. *Social Protection Discussion Paper Series*. Available online <https://documents1.worldbank.org/curated/en/636921468765021121/pdf/multi0page.pdf>.
- Augenti N, Cosenza E, Dolce M, Manfredi G, Masi A, Samela L. 2004.** Performance of school buildings during the 2002 Molise, Italy, *Earthquake*, <https://doi.org/10.1193/1.1769374>.
- Benedetti D, Petrini V. 1984.** On seismic vulnerability of masonry buildings: proposal of an evaluation procedure. *L'Industria delle Costruzioni* **18**:66-74.
- d'Aragona MG, Polese M, Prota A. 2021.** Effect of masonry infill constitutive law on the global response of infilled RC buildings. *Buildings*, **11(2)**:57. <https://doi.org/10.3390/buildings11020057>.
- Dautaj A, Kadiri Q, Naser Kabashi N. 2018.a.** Experimental study on the contribution of masonry infill in the behavior of RC frame under seismic loading. *Engineering Structures*, **165**: 27-37. <https://doi.org/10.1016/j.engstruct.2018.03.013>.
- Dautaj A, Krasniqi C, Sadikaj A, Shatri B, Kabashi N. 2018b.** Experimental study on strengthening effects of glass fibre-reinforced polymers on masonry infilled reinforced concrete frames. *European Journal of Environmental and Civil Engineering*, **25(2)**: 322–336. <https://doi.org/10.1080/19648189.2018.1528893>.

- Falcão Moreira R, Varum H, Castro JM. 2023.** Influence of masonry infill walls on the seismic assessment of non-seismically designed RC framed structures. *Buildings*, **13(5):** 1148. <https://doi.org/10.3390/buildings13051148>.
- Kabashi N, Krasniqi C, Dautaj A, Kadiri Q. 2016.** Masonry structures confinement with glass fibre reinforcement polymers. *Recent*, **17, no. 3(49):** Available on line: <https://www.recentonline.ro/049/b-08-Kabashi-R49.pdf>.
- Leal-Graciano JM, Quiñónez B, Rodríguez-Lozoya HE, Pérez-Gavilán JJ, Lizárraga-Pereda JF. 2020.** Use of GFRP as retrofit alternative for confined masonry walls with window opening subjected to in-plane lateral load. *Engineering Structures*, **223**, <https://doi.org/10.1016/j.engstruct.2020.111148>.
- Paulay T, Priestly MJN. 1992.** Seismic design of reinforced concrete and masonry buildings. DOI: 10.1002/9780470172841, John Wiley & Sons, Inc.
- Santarsiero G, Masi A, Manfredi V, Giuseppe Ventura G. 2021.** Requalification of RC Frame apartment buildings: Comparison of seismic retrofit solutions based on a multi-criteria approach. *Sustainability*, **13(17):** 9962. *Sustainability*, <https://doi.org/10.3390/su13179962>.
- Sarker P, Begum M, Nasrin S. 2011.** Fiber Reinforced Polymers for Structural Retrofitting: A Review. *Journal of Civil Engineering (IEB)*, **39 (1):** 49-57. <https://priyankasarker.com/wp-content/uploads/2017/09/3901004.pdf>.
- Scupin A, Vacareanu R. 2023.** Seismic risk reduction through retrofitting of school masonry buildings from Romania. *Frontiers in Built Environment*, **8:** <https://doi.org/10.3389/fbuil.2022.1104234>.
- Yavartanoo F, Kim Ch-S, Kang THK. 2025.** Cost-effective retrofitting method for dry-stack masonry walls using fiber-reinforced polymers. *The International Journal of Concrete Structures and Materials*, **19, (48):** DOI:10.1186/s40069-025-00792-2.

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